Some astrophysical implications of sterile neutrinos

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T-8

LANL Cosmology Day

April 15, 2004

Outline

- Why sterile neutrinos?
- Cosmological sterile neutrinos with non-thermal abundances and spectra
- Sterile neutrinos and the *r*-process in supernovae

Why sterile neutrinos?

- Three active neutrinos $\rightarrow$ two mass splittings
- Solar neutrinos are fit with

$$\Delta m^2_{\odot} \sim (a\ few) \times 10^{-5} eV^2$$

- Atmospheric neutrinos are fit with

$$\Delta m^2_{\rm atm} \sim (2-3) \times 10^{-3} eV^2$$

- LSND suggests another mass splitting; if confirmed by mini-BOONE, would mean the *presence of one or more extra states*

Why sterile neutrinos?

- Quark and lepton sectors:

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad u_R \quad d_R \quad \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \quad \nu_R ? \quad e_R$$

No gauge quantum numbers (strong, weak, or EM); Possibly interacts ("mixes") with ν_L via mass term

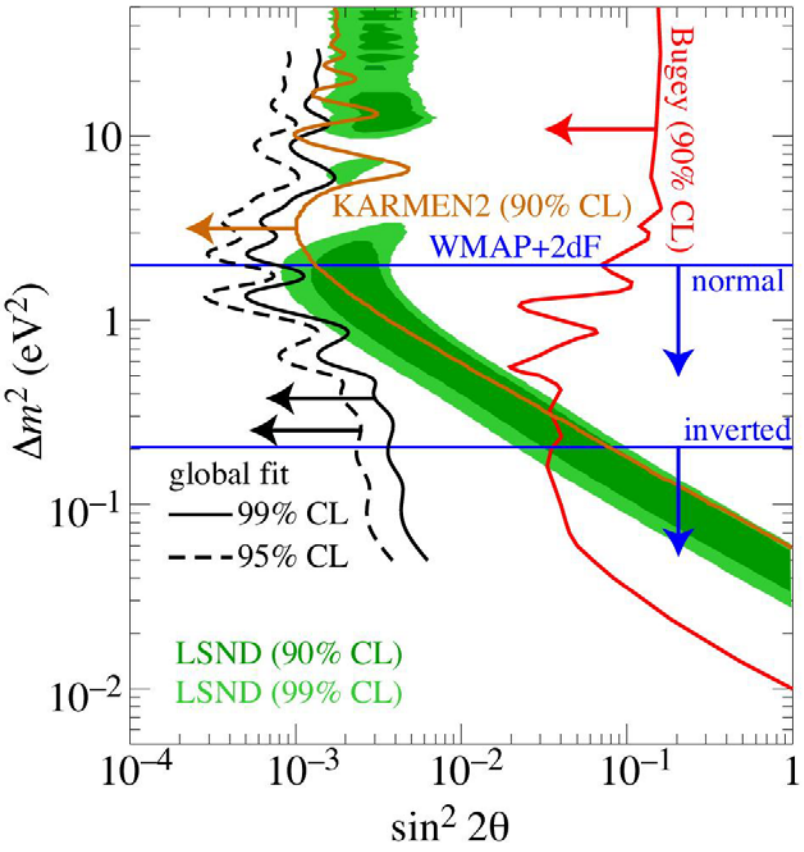
- General mass matrix:

$$\begin{pmatrix} m_L & m_D \\ m_D & m_R \end{pmatrix} \begin{matrix} \nu_L \\ \nu_R \end{matrix}$$

- Theoretical prejudice says that m_R is large, but honestly we don't know $\Rightarrow$ *in general, three active + three sterile neutrinos*

Cosmological sterile neutrino

- It is tempting to conclude that WMAP excluded mass splitting > 1 eV



Murayama, Piece, PLB 2004

- However, sterile neutrino may be produced with a non-thermal abundance and energy spectrum!

Explicit example

X. Shi and G. Fuller, PRL 1999

- Imagine one has a (ν_a, ν_s) system in the early Universe
- The vacuum splitting between the states is $\Delta m^2/2E$
- The matter potential is

$$V \sim G_F T^3 [L_0 + 2L_{\nu_\alpha} + \sum_{\beta \neq \alpha} L_{\nu_\beta}] + O(G_F^2 T^5)$$

receives a contribution L_0 from baryonic and e^+e^- asymmetry and from the proposed *preexisting lepton # asymmetry*

Main idea

- A the Universe cools, neutrinos go through a resonance condition

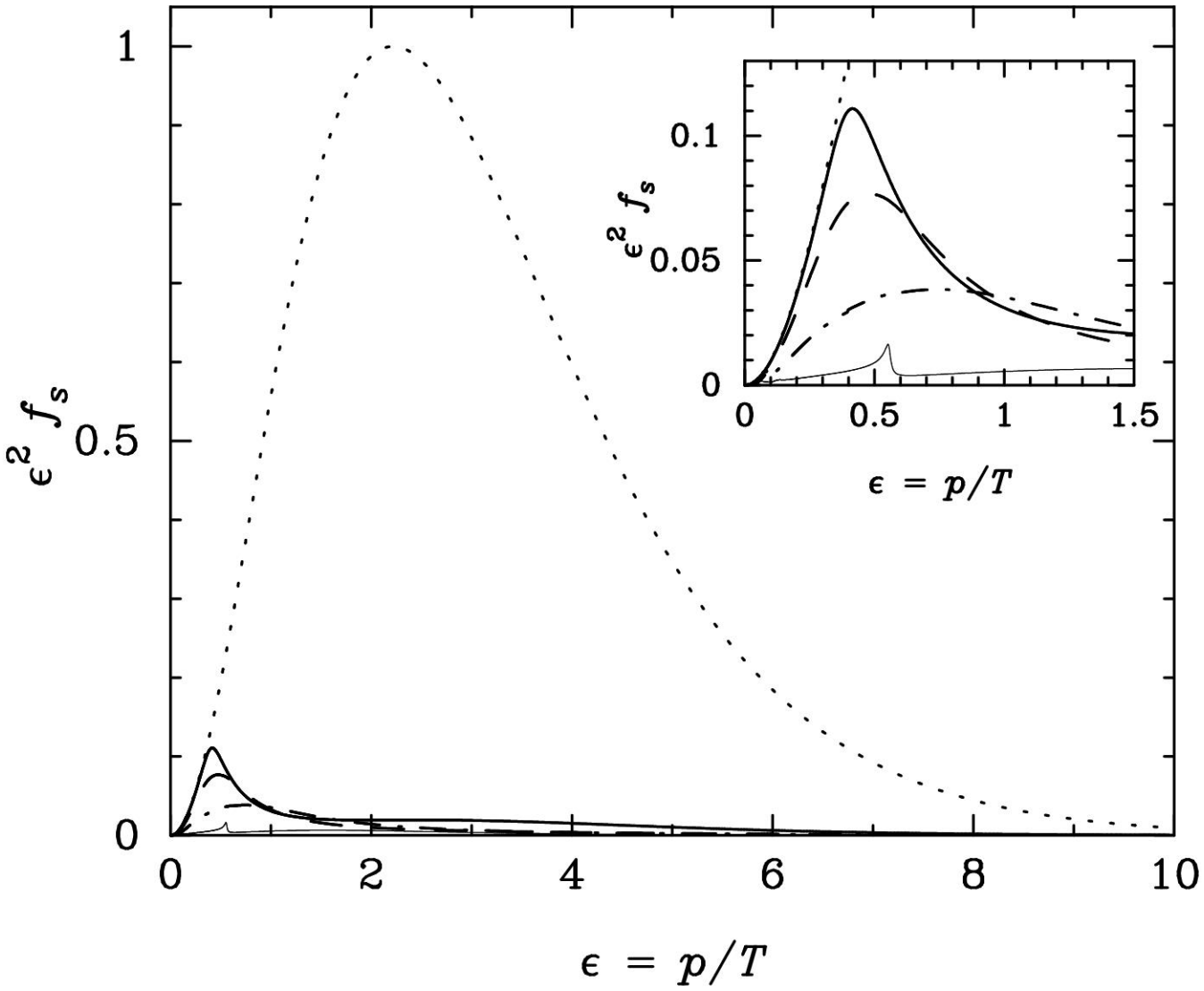
$$\Delta m^2/2E \sim G_F T^3 [2L_{\nu_\alpha} + \sum_{\beta \neq \alpha} L_{\nu_\beta}]$$

- Low energy active neutrinos are converted into sterile first

- The process proceeds until the initial lepton asymmetry in the active states disappears
- The conversion proceeds for either sign of the asymmetry
- Asymmetry of the order 10^{-3}-10^{-2} is sufficient

Non-thermal spectrum

- The result is a non-thermal spectrum



K. Abazajian, G. Fuller, M. Patel PRD 2001

Supernova and r-process

- Supernova explosion is a primary candidate for a place where the synthesis of heavy elements occurs via the *r*-process

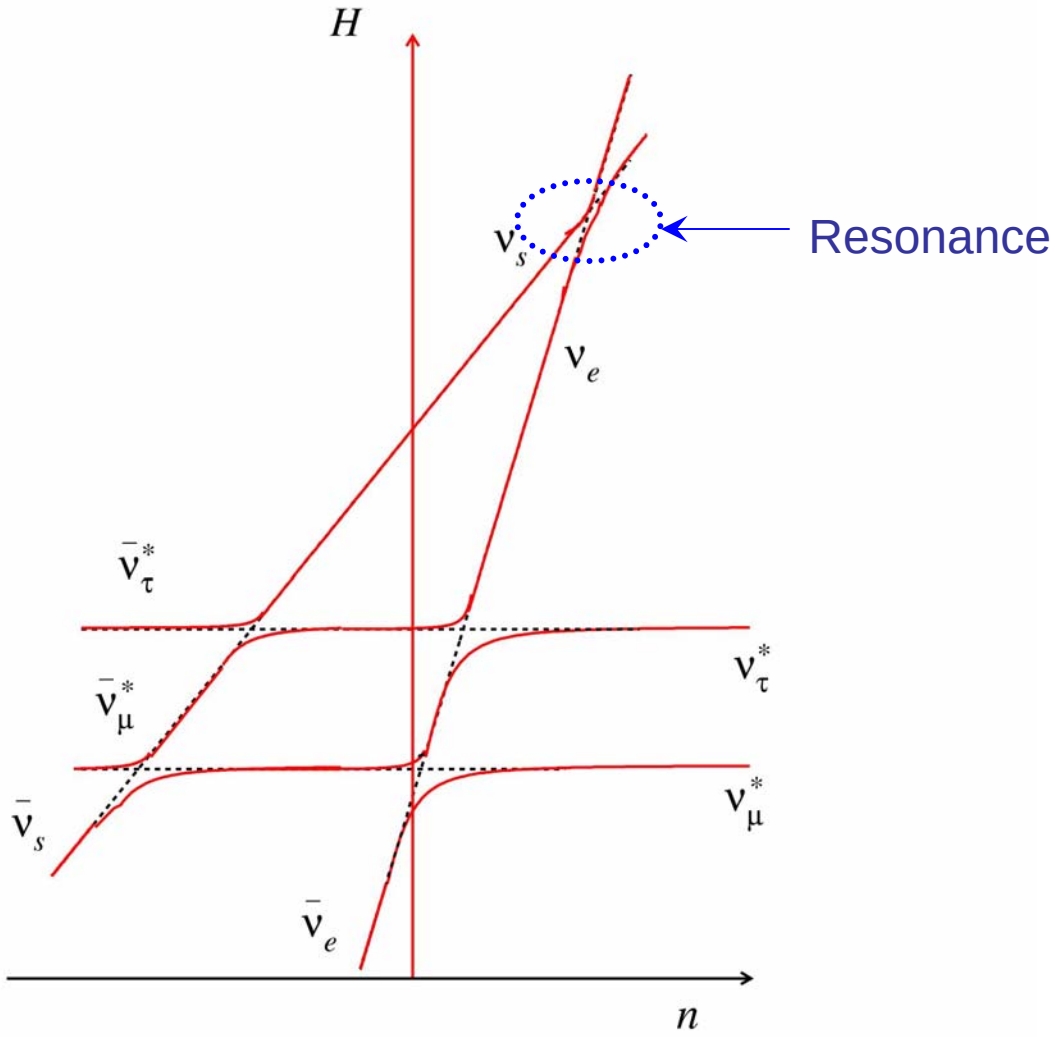
- The *r*-process is operative in the neutron-rich environment

- However, the flux of electron neutrinos leads to a reaction

$$\nu_e + n \rightarrow p + e^-$$

- Since the *r*-process can happen at $T \sim$ 0.25 MeV, *p*'s and *n*'s quickly bind in ^{4}He ("α effect")

Sterile neutrino level-crossing



O. Peres and A. Smirnov, Nucl. Phys. B 2001

r-process saved

- Electron neutrinos can be converted into sterile, allowing the *r*-process to proceed

  G. McLaughlin, J. Fetter, A. Balantekin and G. Fuller, PRC 1999; Astropart. Phys., 2003

- “Sterile neutrino may even be the reason why we have gold rings, tin cans, atomic bombs, and lead shielding”